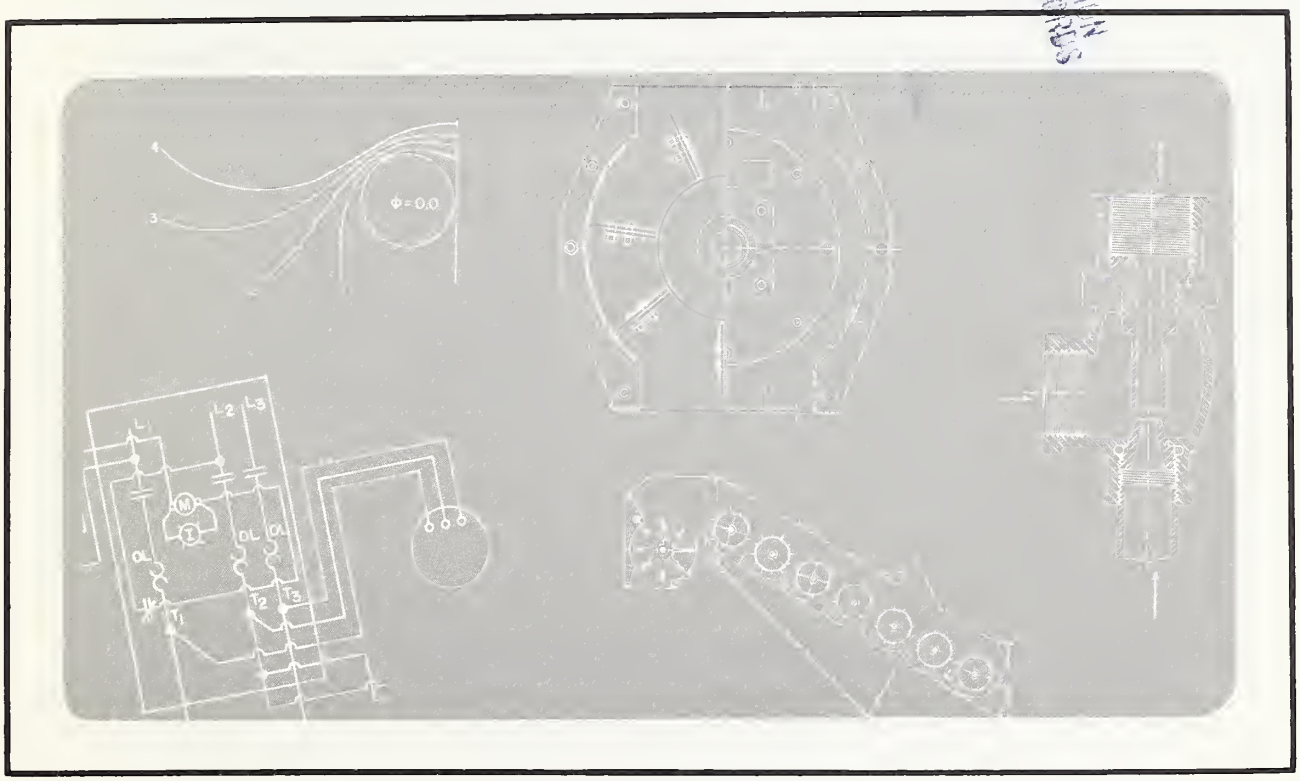
ISSN 0193-3728

Reducing Chilling Injury in Grapefruit by Prestorage Conditioning



U.S. Department of Agriculture
Agricultural Research Service
Advances in Agricultural Technology • AAT-S-25/June 1982

The authors gratefully acknowledge the assistance of Victor Chew, Agricultural Research Service, for conducting the statistical analyses, and the Florida Citrus Commission, Lakeland, Fla., for supplying the fruit.

This publication is available from the U.S. Horticultural Research Laboratory, 2120 Camden Rd., Orlando, Fla. 32803.

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Agricultural Research Service, Advances in Agricultural Technology, Southern Series, No. 25, June 1982.

Published by Agricultural Research Service (Southern Region), U.S. Department of Agriculture, P.O. Box 53326, New Orleans, La. 70153.

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Reducing Chilling Injury in Grapefruit by Prestorage Conditioning

By T. T. Hatton and R. H. Cubbedge[1]

ABSTRACT

Continuous storage of early, midseason, and late 'Marsh' and 'Ruby Red' grapefruit (*Citrus paradisi* Macf.) at 1° C for 28 days resulted in considerable chilling injury, whereas first exposing the fruit for 7 days to 10°, 16°, or 21° C before storage at 1° C significantly reduced chilling injury. Similar reductions were obtained by gradually lowering the temperature to 1° C after conditioning for 7 days. Chilling injury took two forms, pitting or discoloration of the rind. Exposure to 40% carbon dioxide for 3 days at 21° C also reduced chilling injury during storage at 1° C for 25 days, but carbon dioxide increased decay after storage to unacceptable levels. Decay, predominantly caused by *Penicillium digitatum* Saac., was negligible during storage but developed later during the holding periods at 21° C, and was often related to the amount of chilling injury. Index terms: chilling injury, decay, grapefruit, oranges, shipping, storage.

INTRODUCTION

Chase et al. (1966) established that the proper temperature for storing grapefruit (*Citrus paradisi* Macf.) is 16° C for early fruit and 10° C for mid- and late-season fruit. At lower temperatures, the fruit are damaged by disorders known as chilling injury (CI). Chilling injury takes two forms (Lutz and Hardenburg 1968): one prevails near 4° C and is typified by depressions or pits in the surface of the rind, and the other form is common near 0° C and is characterized by brown "stains" on the rind (fig. 1). Except for CI, low-temperature (in this paper, "low temperature" means 1° C) storage would have several advantages: reduction of decay, extension of storage life, and the possibility of storing grapefruit with oranges. (The recommended storage temperature for Florida oranges is 0° C.)

Hawkins (1921) was the first to note that temperature conditioning of grapefruit prior to low-temperature storage reduced CI. Later, Hawkins and Barger (1926) recommended that fruit be "cured" at 18° to 27° C, with relative humidity from 55% to 65%, for 1 to 2 weeks before storing at 0° C. Brooks and McColloch (1936) found that holding grapefruit at 16° to 24° C before storing at 2° C resulted in decreased pitting, but holding at 10° C before storing at lower temperatures had no effect on the development of pitting after 8 weeks or more of storage. A delay of 7 to 10 days at 16° to 24° C before storage at 0° and 4° C produced less CI than a delay of 2 days or 2 weeks. Grierson (1974) reported that CI of 'Marsh' grapefruit was diminished by holding the fruit for 48 hours at 29° C and about 95% relative humidity prior to storage at 4.5° C for 44 days. In our prelimi-

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FIGURE 1.—Chilling injury to grapefruit. Brown discoloration of the rind ("staining") is common near 0° C (left photo). Near 4° C, chilling injury commonly takes the form of rind pitting (center). A sound grapefruit is shown at right.

nary studies (Hatton et al. 1975; Hatton and Cubbedge 1975, 1980), we too have found that temperature conditioning reduces CI. Holding for 3 to 7 days at 21° C reduced CI in grapefruit stored at 4.5° C for 8 and 12 weeks, respectively. In another test, storing near 0° C for 28 days resulted in excessive CI and subsequent decay after removal from storage, whereas "curing" the fruit for 7 days at near 16° C prior to storing near 0° C for 21 days resulted in little or no CI or subsequent decay. Another test showed that CI could be prevented or significantly reduced during storage at 1° C by first conditioning the fruit for 7 days at 10° or 15° C and 85% to 90% relative humidity; conditioning temperatures higher than 15° C (21° and 30° C) and fewer conditioning days (2 and 4) increased CI.

Prestorage treatment in carbon dioxide has also been shown to reduce CI of grapefruit. Brooks and McColloch (1936) found that holding fruit for 20 to 48 hours in atmospheres containing 20% to 45% CO_2 prior to low-temperature storage resulted in decreased pitting; best results were obtained with the longer treatments and higher percentages of CO_2. We noted (Hatton et al. 1972) that midseason fruit exposed to 20% CO_2 for 14 days had less pitting than did untreated fruit after 8 and 12 weeks' storage at near 4° C. We also reported (Hatton and Cubbedge 1974) that prestorage exposure to 10% CO_2 for 1 and 7 days reduced CI of early grapefruit stored for 4 weeks at near 4° C, and that (Hatton et al. 1975) prestorage treatments in 10%, 20%, and 40% CO_2 for 3 and 7 days at 21° C significantly reduced CI in grapefruit stored at 4° C for 8 and 12 weeks, respectively. (Fruit stored continuously at 4° C in air, without the prestorage treatments in CO_2, had excessive CI.) These treatments did not increase the incidence of decay, and they did not affect flavor. A separate test showed that holding late grapefruit in 25% or higher concentrations of CO_2 for 2 to 3 days prior to storage at 4° C induced resistance to CI for 55 days.

Numerous preharvest and postharvest factors other than prestorage temperatures and CO_2 treatments influence the extent of CI in grapefruit (Grierson and Hatton 1977); however, they are not discussed here. The purpose of this study was to determine the practical possibilities of reducing CI of grapefruit during low-temperature storage by the use of temperature and CO_2 conditioning.

TEST DATA

Packed U.S. No. 1 grade 'Marsh' and 'Ruby Red' grapefruit (early, midseason, and late) were obtained over three seasons from packinghouses representing different groves in the Indian River district of Florida and transported to the U.S. Horticultural Research Laboratory, Orlando, where storage testing began on the same day the fruit had been packed. All lots of fruit were collected from 0 to 4 days after picking; the average was 3 days for early fruit because of the time required for commercial degreening, and 1 day for midseason and late fruit. In four 28-day tests, the fruit were treated in various ways, as given in tables 1-4.

After removal from the test storages, the fruit were placed at 21° C and inspected; reinspection was made after 7 days, and to stress the fruit,

they were held for an additional 7 days at 21° C before final inspection.

Inspection included evaluation of CI and decay. CI was rated as slight (the total affected rind-surface area ranged from about 0 to 20 mm in diameter), moderate (the total affected rind-surface area ranged from about 20 to 35 mm in diameter), and severe (the total affected rind-surface area was over 35 mm in diameter). CI was also tabulated as the percentage of fruit affected (tables 1-4).

Chilling injury developed while the fruit were in storage, of course, whereas decay developed mainly during the 14-day holding period at 21° C after storage. Decay during storage was never heavy, but during the holding period it often masked CI, thus preventing the assessment of CI. Therefore, all fruit that decayed were immediately discarded; in tables 1-4 these fruit are accounted for only under decay, not under CI. Decay was predominantly green mold caused by *Penicillium digitatum* Saac., a fungus that enters the grapefruit through injured tissue, as described by Smoot et al. (1971). Some stem-end rot caused by *Phomopsis citri* Fawc. developed in late-season fruit.

Statistically compared (using 2,000 fruit from four groves), 'Ruby Red' and 'Marsh' were equally susceptible to CI; therefore, throughout the study the two cultivars were treated alike, and the data were combined.

Palatability tests were conducted by a panel at the end of each test. Regardless of treatment, all fruit were considered acceptable. Taste differences among treatments were not determined.

Test 1: Early Grapefruit

The early-season grapefruit conditioned for 7 days at 16° C before storage at 1° C for 21 days did not have significantly more CI than the fruit stored continuously for 28 days at the conventional 16° C (table 1). However, the fruit stored continuously for 28 days at the low temperature or conditioned for 2 days at 29° C before low-temperature storage for 26 days had significantly more CI than the fruit conditioned at 16° C and then stored at the low temperature. All CI consisted of brown staining, of which 44% was slight, 32% was moderate, and 24% was severe. Decay during the holding periods progressively increased and followed the same trend as CI.

Test 2: Midseason and Late Grapefruit

The midseason and late grapefruit conditioned for 7 days at either 10° or 16° C, or conditioned at 16° C followed by a gradual lowering of the temperature before low-temperature storage, did not have significantly more CI than fruit stored continuously for 28 days at the conventional 10° C (table 2). However, the fruit stored continuously for 28 days at low temperature had significantly more CI than the fruit from other conditioning and storage treat-

Table 1.—Test 1: Chilling injury to early Florida grapefruit stored under various conditions, and subsequent decay[1]

Storage treatment (°C)	Chilling injury after storage (%)	Decay after holding (21° C) 7 days (%)	Decay after holding (21° C) 14 days (%)
Conventional:			
28 days at 16°	0.0 b	4.6 b	5.8 b
Continuous low temperature:			
28 days at 1°	37.2 a	17.1 a	29.8 a
Conditioning + low temperature:			
7 days at 16° + 21 days at 1°	7.7 b	4.5 b	11.6 b
2 days at 29° + 26 days at 1°	38.2 a	13.5 a	24.6 a

[1]Each value represents the percentage of 2,125 fruits, 125 from each of 17 groves, harvested in October, November, and December. Data followed by different letters in a column are significantly different at the 5% level (Duncan's multiple-range test). Relative humidity during storage and holding ranged from 88% to 92% at 1° C and from 80% to 92% at 16° C and above.

Table 2.—Test 2: Chilling injury to midseason and late Florida grapefruit stored under various conditions, and subsequent decay[1]

Storage treatment (°C)	Chilling injury after storage (%)	Decay after holding (21° C) 7 days (%)	Decay after holding (21° C) 14 days (%)
Conventional:			
28 days at 10°	0.3 b	11.6 a	15.8 bc
Continuous low temperature:			
28 days at 1°	15.8 a	13.0 a	19.3 abc
Conditioning + low temperature:			
2 days at 29° + 26 days at 1°	14.9 a	13.7 a	24.2 a
7 days at 16° + 2 days at 7° + 2 days at 4° + 17 days at 1°	.4 b	13.6 a	21.9 ab
7 days at 16° + 21 days at 1°	1.2 b	11.2 a	18.5 abc
7 days at 10° + 21 days at 1°	1.1 b	8.1 a	14.3 c

[1]Each value represents the percentage of 1,856 fruits, 116 from each of 16 groves, harvested in January, February, March, and April. Data followed by different letters in a column are significantly different at the 5% level (Duncan's multiple-range test). Relative humidity during storage and holding ranged from 88% to 92% at 1° to 10° C and from 80% to 92% at 16° C and above.

ments. Conditioning for 2 days at 29° C was also ineffective in reducing CI. Ninety-nine percent of CI was brown staining, of which 69% was slight, 18% was moderate, and 13% was severe. Decay during the holding periods progressively increased but did not differ significantly among treatments.

Test 3: Midseason and Late Grapefruit

Conditioning of midseason and late grapefruit for 7 days at 10° C or gradually lowering the temperature from 10° C before storing at low temperature resulted in about the same CI as storing continuously at the conventional 10°C (table 3). Conditioning for 3 days at 21° C in 40% CO_2 before low-temperature storage was also effective in reducing CI, whereas without CO_2, CI was significant. CI consisted of 55% pitting and 45% brown staining; most of the pitting occurred in fruit stored continuously at 1° C. Pitting was rated 62% slight, 24% moderate, and 14% severe; brown staining was rated at 65% slight, 22% moderate, and 13% severe. With the exception of the continuous low-temperature storage, the CO_2 treatment, after both 7 and 14 days' holding, resulted in significantly more decayed fruit than did the other treatments; otherwise no significant differences existed among treatments.

Test 4: Early Grapefruit

No significant difference was found in CI among treatments, except that fruit stored continuously at low temperature had significantly more CI (table 4). This fruit had 49% pitting CI and 51% brown-staining CI, with most of the pitting in fruit from the continuous low-temperature storage. Pitting was rated 44% slight, 23% moderate, and 33% severe, respectively; brown staining was rated 39% slight, 34% moderate, and 27% severe. Decay progressively increased during the holding periods. There were no significant differences among treatments until day 14, when the fruit from the continuous low-temperature storage showed significantly more decay.

CONCLUSIONS

Prestorage conditioning for 7 days at 10°, 16°, or 21° C is effective in reducing CI of grapefruit

Table 3.—Test 3: Chilling injury to midseason and late Florida grapefruit stored under various conditions, and subsequent decay[1]

Storage treatment (°C)	Chilling injury after storage (%)	Decay after holding (21° C) 7 days (%)	Decay after holding (21° C) 14 days (%)
Conventional:			
28 days at 10°	1.3 c	8.5 b	10.2 b
Continuous low temperature:			
28 days at 1°	18.6 a	9.0 ab	13.7 b
Conditioning + low temperature:			
3 days at 21° + 25 days at 1°	8.1 b	8.4 b	11.5 b
3 days at 21° in 40% CO_2 + 25 days at 1°	3.7 c	12.5 a	18.1 a
7 days at 10° + 2 days at 7° + 2 days at 4° + 17 days at 1°	2.8 c	6.2 b	9.2 b
7 days at 10° + 21 days at 1°	3.2 c	6.5 b	10.6 b

[1]Each value represents the percentage of 2,760 fruits, 120 from each of 23 groves, harvested in January, February, March, and May. Data followed by different letters in a column are significantly different at the 5% level (Duncan's multiple-range test). Relative humidity during storage and holding ranged from 88% to 92% at 1° to 10° C and from 80% to 92% at 16° C and above.

Table 4.—Test 4: Chilling injury to early Florida grapefruit stored under various conditions, and subsequent decay[1]

Storage treatment (°C)	Chilling injury after storage (%)	Decay after holding (21° C) 7 days (%)	Decay after holding (21° C) 14 days (%)
Conventional:			
28 days at 16°	0.0 b	5.5 a	9.7 ab
Continuous low temperature:			
28 days at 1°	51.7 a	7.1 a	23.9 a
Conditioning + low temperature:			
7 days at 21° + 2 days at 7° + 2 days at 4° + 17 days at 1°	1.0 b	4.2 a	5.9 b
7 days at 21° + 21 days at 1°	.0 b	3.8 a	5.4 b
7 days at 16° + 2 days at 7° + 2 days at 4° + 17 days at 1°	1.0 b	5.8 a	7.5 ab
7 days at 16° + 21 days at 1°	3.8 b	2.8 a	5.8 b

[1]Each value represents the percentage of 240 fruits, 120 from each of 2 groves, harvested in December. Data followed by different letters in a column are significantly different at the 5% level (Duncan's multiple-range test). Relative humidity during storage and holding ranged from 88% to 92% at 1° to 7° C and from 80% to 92% at 16° C and above.

during subsequent low-temperature storage for up to 21 days. Gradually lowering the temperature after such conditioning is equally effective for up to 17 days, as in tests 2–4. The use of CO_2, as in test 3, is precluded because of excessive fruit decay after storage. (Too, it is an expensive treatment requiring a monitoring system.) Temperature conditioning of grapefruit followed by low-temperature storage as described in this paper is feasible in storage houses and ships, and 21 days is adequate even for most overseas shipments. If grapefruit are preconditioned, they can be successfully stored and shipped with oranges.

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1982—569-036/33C

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